Strain-Free Growth Of Cu Whiskers On A Ru(0001) Substrate

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Beamline(s): **X22C**

Introduction: Epitaxial film growth of dissimilar materials usually introduces strain due to the natural lattice mismatch of the materials. As the film becomes thicker, the energy pent up in this strain increases until eventually dislocations must form to provide relief. For Cu deposited on Ru(0001), strain relief begins in the first two layers, which form a stripe phase by reducing the Cu-Cu separation along one-dimension (ref. 1). We have studied the Cu islands, which appear for depositions greater than two layers, to determine their strain, dynamics, and morphology.

Methods and Materials: Structures and dynamics were examined using x-ray diffraction at beamline X22C at the National Synchrotron Light Source. Monochromatic x-ray beams with energies from 8-10.5 keV were passed through a UHV vacuum chamber, with base pressure of $1x10^{-10}$ Torr, by means of a thin beryllium window. The UHV chamber is incorporated in a six-circle diffractometer. At the center of the diffractometer, a polished Ru(0001) crystal was suspended from tungsten wires. In situ, surface preparation involved Ar sputtering, annealing in oxygen, then annealing in vacuum to 1725 K. High purity Cu was evaporated onto the Ru surface using a resistively heated Knudsen cell, which could be operated during diffraction experiments.

Results: For depositions above two layers, two new diffraction rods appear normal to the surface. Based on their location, we assign these diffraction peaks to islands of bulk-like Cu, with (1,1,1) orientation normal to the surface and two in-plane orientations. One orientation is aligned with the substrate, the second rotated 0.9 degrees. The bulk-like diffraction peaks are not commensurate with the substrate Ru, but rapidly develop the in-plane wavevector of bulk Cu. Thus by the time three layers of Cu have been deposited, these islands show no in-plane strain. It follows that the stripe phase formed by the first two layers of Cu is very efficient in accommodating the 5.8% strain introduced by the Cu-Ru lattice mismatch.

Despite the appearance of bulk-like islands, stripe phase diffraction from the first two Cu layers is still observed. In fact, the 2-layer stripe phase persists beyond deposition of 25 layers of Cu. This is because the bulk-like Cu islands do not cover the entire surface and are much taller than they are wide. With this high aspect ratio, the bulk-like islands could be described as whiskers extending from the surface. This morphology is evidenced by the rapid development of crystalline diffraction normal to the surface in the Cu film. Fig. 1 plots the integrated intensity of a Cu bulk-like crystal truncation rod against momentum transfer normal to the surface, q_z, after deposition of 4 layers of Cu at 720 K. Strong diffraction maxima are observed at q_z=0.68 and 1.35, when qz is defined relative to the bulk Ru lattice. Relative to bulk Cu, q_z=1 and 2. What is most surprising about these strong diffraction maxima is their width. Noting the logarithmic scale of the vertical axis in Fig. 1, the peak widths correspond to approximately 1/30 of the Cu unit cell. This implies a correlation length of 50 layers. In this instance, deposition of 4 layers of Cu has grown bulk-like islands on average 50 layers high! A simple argument from volume conservation reveals that these islands must be much higher than they are wide.

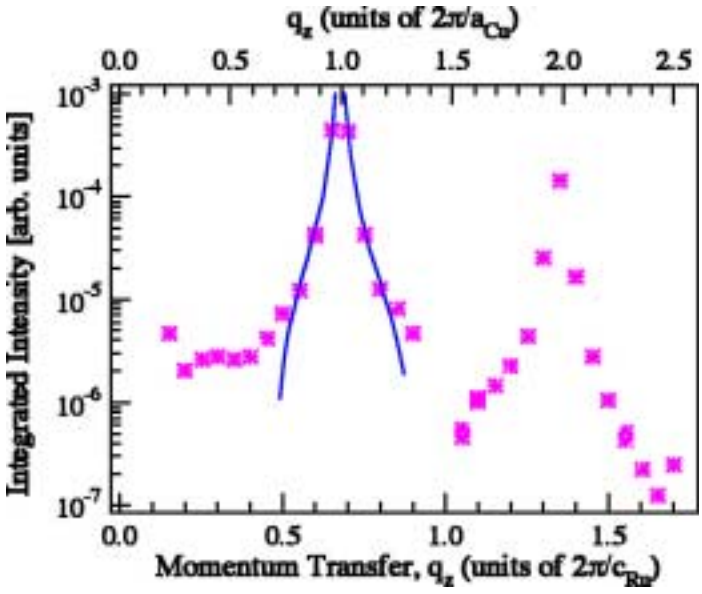

Figure 1. Crystal truncation rod from a Cu bulk-like island after deposition of 4 layers at 720 K.

Conclusions: These results provide direct evidence that at elevated temperatures, Cu grows in a Stransky-Krastanov growth mode, with a two layer critical thickness. The islands which forms are strain-free are much taller than they are wide, forming whisker-like structures.

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